service monitoring times, the time to cease transmissions or move to another channel, and the time to revisit a portion of the spectrum to determine whether it is unoccupied.[82] Even with this relatively simple implementation of a CR technique, developing compliance measurement procedures has proven to be challenging. These procedures must be such that they can be reasonably implemented by the Telecommunication Certification Bodies (TCBs). Furthermore, the procedures need to be comprehensive enough to ensure that the DFS capability adequately protects the radar systems.

NTIA agrees with many of the tests proposed by the Commission in the NPRM for listen-before-talk or sensing CR techniques. However, NTIA believes that there are additional factors that must be included in the compliance measurement procedures. For example, depending on how the listen-before-talk or sensing capability is implemented and the type of data transmissions, the channel loading could have an impact on the compliance measurements. If the listen-before-talk or sensing CR techniques are implemented so that a dedicated period of time is established for spectrum monitoring, the channel loading is not as critical. However, if the spectrum monitoring is performed during the quiet periods between data packet transmissions, the channel loading becomes more critical. This is particularly true if the signal that is to be detected has time-varying characteristics, such as a radar system with an antenna that scans 360 degrees in azimuth. In this situation, the detection process depends on the packet size of the data transmissions. To simulate the channel loading, standard data files should be developed.[83] For Internet Protocol-based systems that employ a variable packet length based on the file being transmitted, it should be sufficient to stream a file that will load the system to 40 to 60 percent of

82. U-NII R&O at Appendix C.

83. A standard Moving Picture Experts Group-2 (MPEG-2) file could be used for the channel loading depending on

its throughput capability. For frame-based systems that employ fixed packet lengths, but vary the transmit/listen time, the transmit/listen ratios should be set to a value that represents the setting used during actual system deployment. Additional parameters that need to be defined for measuring the detection level including whether the measurement is based on peak and/or average power and the measurement interval.[84]

For listen-before-talk and sensing CR techniques to be effective, the test signals used in the compliance measurements must be representative of the signals employed by the licensed radio service in the frequency band that is being monitored. The DFS-equipped U-NII devices are sharing with the radiolocation service, so the test signals are defined by representative radar characteristics such as pulse repetition frequency, pulse width, burst length, burst period, and hopping rate (for frequency hopping radar systems).[85] In frequency bands in which the characteristics of the licensed service are known and not subject to change (*e.g.*, broadcast signals), it may be possible to use these characteristics to assist in signal detection. However, when detecting signals in bands where the characteristics of the licensed service vary over a wide range or can change because of future system developments, the detection should be based solely on received power level exceeding a specified threshold. The actual detection threshold will vary depending on the characteristics of the licensed radio service and the unlicensed device application as well as the operational scenario. The compliance measurements must verify that the signal detection is based on received power level in these situations.

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the device application.

84. For DFS-equipped U-NII devices, detection is based on a maximum power level averaged over a 1 microsecond time period.

85. U-NII R&O at Appendix C-13.

The Commission also identified tests to be included in the compliance measurements for unlicensed devices that employ geo-location techniques. These tests address the ability of the device to correctly identify its location, the ability to access an on-line database of other authorized systems, and the unlicensed device response when the position location is lost. NTIA agrees with the Commission's proposal and recommends an additional test to verify what corrective action will be taken (*e.g.*, cease transmitting, reduce power, move to another frequency) when it is determined that the unlicensed device is within the exclusion areas around the fixed site locations in the on-line database.

NTIA believes that the compliance measurement procedures for devices employing CR techniques need to be developed in an open forum, where private and government entities can participate. This approach is being employed by the government/industry working group, chaired by NTIA, that is addressing the compliance measurement procedures for DFS-equipped U-NII devices operating at 5 GHz. These working group meetings are open to the public and include participants from NTIA, the FCC, the DOD, manufacturers, and the TCBs. This working group has been successful in developing consensus positions that are used to provide guidance to the Commission. The Commission suggests ANSI as a possible organization for developing the compliance measurement procedures. NTIA believes the SDR Forum is another possible organization that can be used to develop compliance measurement procedures for devices employing CR techniques. The SDR Forum meetings are open to the public and have participation from both the private sector and the government.

In the past, because of their simplicity, the compliance measurement procedures for unlicensed devices were typically considered after the development of the service rules. However, given that CR devices can change their electromagnetic characteristics on a near real-time basis, compliance measurements will be more complex. NTIA believes that the compliance measurements are a critical element in ensuring that unlicensed devices employing CR techniques do not interfere with authorized spectrum users. The TCBs are experts in the area of performing the compliance measurements and need to be actively engaged in providing guidance on the technical issues related to device certification for unlicensed devices employing CR techniques. NTIA believes that technological approaches that cannot be verified in the TCB laboratories should not be relied upon for successful spectrum sharing. NTIA recommends that the Commission resolve all of the technical issues related to performing the compliance measurements prior to implementing CR techniques in any frequency band.

XVII. A NEW SUBPART UNDER PART 15 OF THE COMMISSION'S RULES SHOULD BE ESTABLISHED FOR UNLICENSED DEVICES EMPLOYING COGNITIVE RADIO TECHNIQUES.

The ability of CR technologies to adapt a radio's use of the spectrum to the real-time conditions of the operating environment offers regulators, licensees, government agencies, and the public the potential for more flexible, efficient, and comprehensive use of the available RF spectrum. Nevertheless, CR technologies could raise new interference issues that will have to be addressed. Furthermore, unlike conventional unlicensed devices, the compliance measurements for devices employing CR technologies will be much more complicated and will have a greater impact on whether or not a device is compatible with other spectrum users. The NPRM does not address how unlicensed devices that employ CR technologies should be accommodated under the current Part 15 Rules. NTIA recommends that a new subpart within the Commission's Part 15 Rules be established for unlicensed devices that employ CR techniques. This is similar to the approach that was used for unlicensed UWB devices, which also did not fit into the existing Part 15 Rules.

The Commission has adopted a definition for SDRs. NTIA recommends that the Commission consider adopting the following definition for CR:

> *Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets.*

NTIA believes that the Commission should adopt a definition for CR in order to provide regulatory certainty to manufacturers seeking industry investment in these new technologies.

XVIII. UNLICENSED DEVICES CAPABLE OF OPERATING ON NON-PART 15 FREQUENCIES MUST INCORPORATE FREQUENCY SENSING OR GEO-LOCATIOIN CAPABILITIES.

The Commission proposes to allow certification of Part 15 devices that are capable of operating on non-Part 15 frequencies. As part of this proposal, the Commission would require that such devices incorporate DFS to select the appropriate operating frequency based on the country of operation.[86] The Commission also proposes that these devices must incorporate a means to determine the country of operation.[87] The Commission seeks comment on these proposals.

Many of the frequency bands where unlicensed device operation is permitted are not harmonized on a worldwide basis. For example, the 902-928 MHz band is limited to the United States in most cases. With the Commission's recent action in the U-NII proceeding additional spectrum in the 5 GHz bands, unlicensed devices operating on the U.S. channels will be using the same frequency bands as most of the world. However, in the United States, unlicensed device operation is permitted in the 2400-2483.5 MHz as opposed to the 2400-2500 MHz band

86. Cognitive Radio NPRM at ¶ 97.

87. *Id.*

used by most countries.[88] The ability to certify unlicensed devices that could be used on a worldwide basis, or at least in a number of different countries, would eliminate the need for manufacturers to produce multiple versions of a device for use in different countries.

Unlicensed devices can fall into two general categories: devices that are under the control of a central controller (e.g., access point); and devices that are capable of operating without a central control (e.g., peer-to-peer operation). NTIA recognizes the potential benefits of allowing manufacturers to produce one device that can be enabled on a country specific basis to transmit in the authorized spectrum bands of that country. However, the proposal to require DFS technology to be embedded into unlicensed devices capable of operating outside of the Part 15 frequency bands is unnecessary since DFS only looks for an open frequency and has no ability to recognize where it is located. Passive sensing is possible in the case where the central controller is capable of supplying the frequency selection information to the devices, for example, as specified in IEEE 802.11 Task Group (TG)d. However, this does not address devices that can operate without a central controller and it also assumes that the central controller is set to only access frequencies authorized for use in the United States.

If the Commission adopts its proposal to certify unlicensed devices that are capable of using non-Part 15 frequencies, then it should limit this to devices where the central controllers can control the transmit frequencies of the client devices. As part of the device certification process, it is imperative that it be ensured that the central controllers can only operate in the bands authorized for Part 15 operations. For unlicensed devices that operate without a central controller, the device should be required to incorporate geo-location capabilities, such as GPS, in

88. Channels 12 and 13 (2467 MHz and 2472 MHz) of the IEEE 802.11 b/g standard are not used in most cases to avoid problems with out-of-band emissions in the restricted frequency band 2483.5-2500 MHz which is used by the mobile satellite service in the United States.

conjunction with a database, to determine its geographic location. The location information would then be used to control the authorized frequencies that the unlicensed device can use. Furthermore, if the unlicensed device is not capable of determining its geographic location, the device must be restricted from transmitting.

XIX. CONCLUSION

NTIA commends the Commission for initiating this proceeding examining CR technology. NTIA agrees with the Commission regarding the significant benefits that could be gained by employing CR technologies. The NPRM identifies several areas where technical and regulatory issues must be addressed. NTIA supports the Commission's approach, whereby the initial implementation of CR technologies is limited to a few frequency bands primarily used by unlicensed devices. NTIA believes that the experience gained in these frequency bands will help facilitate a much broader implementation of CR technologies while ensuring that existing government and non-government spectrum users are adequately protected from interference. NTIA will continue to work with the Commission and industry to resolve the technical and regulatory issues surrounding the successful implementation of CR technologies.

For the foregoing reasons, NTIA submits these comments

Respectfully submitted,

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APPENDIX A
ASSESSMENT OF POTENTIAL INTERFERENCE TO RADAR SYSTEMS IN THE 5725-5875 MHz BAND FROM HIGHER-POWERED UNLICENSED DEVICES EMPLOYING DYNAMIC FREQUENCY SELECTION

INTRODUCTION

In the Notice of Proposed Rulemaking (NPRM) the Federal Communications Commission (Commission) proposed to permit higher-powered unlicensed device operation in the 5725-5875 MHz band.[1] Under the Commission's proposal, this higher-powered unlicensed device operations would be limited to rural areas or areas where it is determined that spectrum use is limited.[2] The Commission proposed that the unlicensed devices operating in these rural or unused areas employ dynamic frequency selection (DFS)[3] with a detection threshold of 30 dB above the thermal noise floor within a measurement bandwidth of 1.25 MHz.[4]

The Federal Government users in the 5725-5875 MHz band are fixed, transportable, and mobile radar systems operated by the Department of Defense (DoD) that are used primarily for surveillance, test range instrumentation and experimental testing.[5] These radar systems are used extensively in support of national and military test range operations in the tracking and control of manned and unmanned airborne vehicles. As pointed out in the NPRM, many of the installations where these radar systems operate are located in rural areas to avoid interference with other systems.[6] There is also a growing concern regarding potential interference to these radar systems related to their expanding role in support of homeland defense. This expanded role could result in a requirement to deploy radar systems in areas close to cities and highways, potentially increasing interference to the radar systems from unlicensed devices operating at the higher power levels. The potential interference between military radar systems operating in the 5250-5350 MHz and 5470-5725 MHz and Unlicensed National Information Infrastructure (U-NII) devices employing DFS was addressed as part of another Commission rulemaking proceeding.[7]

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1. *Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies*, Notice of Proposed Rulemaking, ET Docket No. 03-108, 18 F.C.C. Rcd. 26859 at ¶ 42 (2003) ("Cognitive Radio NPRM").

2. *Id.* at ¶ 44.

3. DFS is a mechanism that dynamically detects signals from other systems and avoids co-channel operation with these systems.

4. Cognitive Radio NPRM at ¶ 44.

5. The frequency bands from 5250-5925 MHz are allocated on a primary basis to the government radiolocation service.

6. Cognitive Radio NPRM at ¶ 43.

7. *Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, Report and Order, ET Docket No. 03-122, 18 F.C.C. Rcd. 24484 (2003).

A similar analysis must be performed in the 5725-5875 MHz band in order to assess whether the power levels and detection threshold proposed by the Commission are adequate to protect these radar systems.

This appendix describes: the operational scenario for the unlicensed devices and the military radar systems used in the assessment; the technical characteristics of the radar systems and unlicensed devices used in the assessment; and the engineering algorithms used to assess the potential for interference to the radar systems from the DFS equipped unlicensed devices. The analysis will assess whether the proposed power levels and detection threshold is adequate to protect the radar systems.

DESCRIPTION OF UNLICENSED DEVICE DEPLOYMENT

The NPRM does not propose a specific higher powered unlicensed device application in the 5725-5875 MHz band. However, it does indicate that local area networks and Wireless Internet Service Providers (WISP) would benefit from the proposed higher power levels.[8] In another rulemaking the Commission expects that the primary use of unlicensed devices in rural areas would be to provide wireless Internet services such as those provided by WISPs.[9] The higher power levels proposed by the Commission will in all likelihood not be used in hand-held or laptop unlicensed device application because of radiation hazard and battery life issues.

In this assessment, the number of unlicensed devices will be varied and the locations of the unlicensed devices will be randomly distributed in a circular region defined by a radius of 25 kilometers. It is assumed that all of the unlicensed devices are transmitting and are co-channel with the radar system. The antenna heights will be randomly assigned to each unlicensed device, using a uniform probability distribution. The range of the antenna heights considered in the analyses are: 6 to 10 meters; 10 to 40 meters, or 40 to 100 meters.

DESCRIPTION OF RADAR DEPLOYMENT

Two aspects are considered when positioning the radar with time, one taking into account the physical location of the radar and the other taking into account the scanning ability of the radar beam. The radars operating in the 5725-5875 MHz band include: ground-based (scanning and tracking), airborne, and maritime systems.[10] In the technical studies examining interference from DFS equipped U-NII devices, it was determined that radars employing tracking beam scans

8. Cognitive Radio NPRM at ¶ 38. The proposed power levels would increase the coverage of by a factor of 6.

9. *Additional Spectrum for Unlicensed Services Below 900 MHz and in the 3 GHz Band*; *Amendment of the Commission's Rules with Regard to the 3650-3700 MHz Government Transfer Band,* Notice of Proposed Rulemaking, ET Docket No. 04-151; ET Docket No. 02-380; ET Docket No. 98-237, FCC 04-100, 2004 FCC LEXIS 2071, at ¶ 43 (2004) ("3650-3700 MHz NPRM").

10. Recommendation ITU-R M.1638, *Characteristics of and Protection Criteria for Sharing Studies for Radiolocation, Aeronautical Radionavigation and Meteorological Radars Operating in the Frequency Bands Between 5250 and 5850 MHz* (2003).

were the most susceptible to interference. A tracking beam scan was defined as a beam pointing at the horizon in any direction that then moves directly overhead and opposite to the starting location to the horizon. The location of the tracking radar and the azimuth of the beam will be varied to determine where the highest interference level occurs.[11]

UNLICENSED DEVICE TECHNICAL CHARACTERISTICS

Unlicensed Device Power Levels

The Commission proposed two emission levels for the higher-powered unlicensed devices operating in the 5725-5875 MHz band: 1) transmitter power of 6 watts and 2) a field strength limit of 125 milliVolts per meter (mV/m) at a reference distance of 3 meters.[12] Converting these emission levels to equivalent isotropically radiated power (EIRP) levels results in 38 dBm (6 watts) and 6.6 dBm (125 mV/m). In this assessment, two transmitter power distributions are considered: 1) 50% of the unlicensed devices operating at the higher EIRP level of 38 dBm and 50% operating at the lower EIRP level of 6 dBm; and 2) 100% of the unlicensed devices operating at the higher EIRP level of 38 dBm.

Unlicensed Device Transmitter and DFS Detection Bandwidths

There are two bandwidths of concern for unlicensed devices employing DFS. The first bandwidth is the transmitter bandwidth used by the unlicensed device. The second is the bandwidth used to measure the DFS detection threshold. The Commission did not define the bandwidth for the unlicensed device. In this assessment, three transmitter bandwidths are considered for the unlicensed devices: 1 MHz, 6 MHz, and 18 MHz. The 1 MHz bandwidth of the unlicensed device is matched to the radar receiver bandwidth of 1 MHz, which represents a worst case from an interference perspective. The 6 MHz bandwidth is representative of the transmit bandwidth used by fixed wireless access systems. The 18 MHz bandwidth is consistent with that employed by U-NII devices.

As discussed in the NPRM, the Commission defined the measurement bandwidth for the DFS detection to be 1.25 MHz.

Unlicensed Device Antenna Gain Patterns

In another rulemaking, the Commission stated that in rural areas unlicensed devices would typically employ omnidirectional antennas in order to achieve the most uniform coverage of a particular geographic area.[13] The unlicensed device antenna pattern used in this assessment is omnidirectional in the azimuth plane.

11. Each radar location/azimuth location and distribution of unlicensed device locations is defined as a trial.

12. Cognitive Radio NPRM at ¶ 38.

13. 3650-3700 MHz NPRM at ¶ 43.

The unlicensed device antenna pattern in elevation orientations was determined by examination of unlicensed device antenna patterns. The unlicensed device antenna elevation pattern is defined in terms of the antenna gain in dBi as a function of the elevation angle (φ) in degrees. The antenna elevation pattern used in this analysis is described below in Table A-1.

Table A-1. Unlicensed Device Elevation Antenna Pattern

Elevation angle (degrees)	Gain (dBi)
$45 < \varphi \leq 90$	–4
$35 < \varphi \leq 45$	–3
$0 < \varphi \leq 35$	0
$-15 < \varphi \leq 0$	–1
$-30 < \varphi \leq -15$	–4
$-60 < \varphi \leq -30$	–6
$-90 < \varphi \leq -60$	–5

RADAR TECHNICAL CHARACTERISTICS

Radar Transmitter and Receiver Characteristics

Representative technical and operational characteristics of the radar systems used in this analysis are provided in Recommendation ITU-R M.1638. The ITU-R Recommendation provides the transmitter power level, mainbeam antenna gain, transmitter and receiver bandwidths, and receiver noise figure for each type of radar included in the analysis. Table A-2 provides the characteristics of the radar transmitter and receiver used in this analysis.

Table A-2. Radar Transmitter and Receiver Characteristics

Parameter	Value
Frequency	5725 MHz
Transmitter Power	250,000 Watts
Transmitter Bandwidth	1 MHz
Receiver Bandwidth	1 MHz
Receiver Noise Figure	6 dB
Transmitter and Receiver Insertion Losses	2 dB
Mainbeam Antenna Gain	38.3 dBi
Antenna Height	20 meters

Radar Antenna Gain Pattern

A model representing the envelope of the gain of typical directional antennas is used to determine the radar antenna gain in the azimuth and elevation orientations.[14] The model gives the antenna gain as a function of off-axis angle (θ) for a given main beam antenna gain (G). Figure A-1 illustrates the general form of the antenna gain distribution. The equations for the angles θ_M (first side-lobe shelf), θ_R (near side-lobe region), and θ_B (far side-lobe region) are given in Table A-3. The antenna gains, as a function of off-axis angle, are given in Table A-4. The angle θ is in degrees and all gain values are given in terms of decibels relative to an isotropic antenna (dBi).

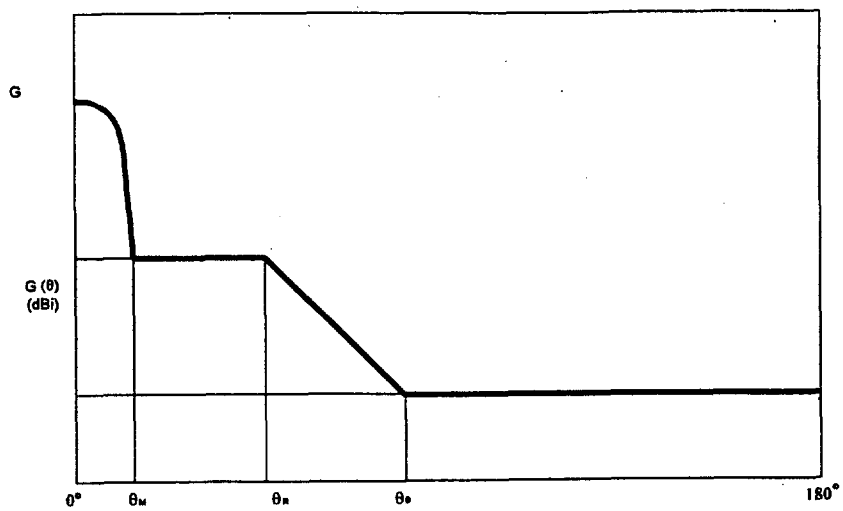

Figure A-1.

Table A-3. Angle Definitions

$\theta_M = 50\,(0.25\,G + 7)^{0.5}/10^{G/20}$
$\theta_R = 250/10^{G/20}$
$\theta_B = 48$

Table A-4. Equations for Radar Antenna Gain

Angular interval (degrees)	Gain (dBi)
0 to θ_M	$G - 4 \times 10^{-4}\,(10^{G/10})\,\theta^2$
θ_M to θ_R	$0.75\,G - 7$
θ_R to θ_B	$53 - (G/2) - 25\log(\theta)$
θ_B to 180	$11 - G/2$

14. Joint Spectrum Center, JSC-CR-96-016B, *JSMS$_W$ Interference Analysis Algorithms,* at 2-11 (April 1998).

This model will employ a far-field antenna pattern for the radar systems, even though the unlicensed devices will sometimes be located within the antenna near-field. This approach is used because of the complexity of modeling the radar antenna in the near-field, and will provide results that may be more conservative than those that would be expected if the near-field effects could be easily modeled.

DESCRIPTION OF ANALYSIS METHODOLOGY

This section describes the engineering algorithms that are used in the model. Radar systems and unlicensed devices operating co-channel in proximity could produce a scenario where mutual interference is experienced. The methodology provided in ITU-R recommendation M.1461 is used to compute the received interference power levels at the radar and unlicensed device receivers.[15] A DFS algorithm may provide a means of mitigating this interference by causing the unlicensed devices to migrate to another channel once a radar system has been detected on the currently active channel. This model first considers the interference caused by the radar to the unlicensed device at the output of the unlicensed device antenna. If the received interference power level at the output of the unlicensed device antenna exceeds the DFS detection threshold, the unlicensed device will cease transmissions and move to another channel. The model then computes the aggregate interference to the radar from the remaining unlicensed devices. Each of the technical parameters used in the model and the radar interference criteria will also be described.

This received signal level from the radar at the output of the unlicensed device antenna is evaluated by using Equation A-1.

$$I^U = P_{Radar} + G_{Radar} + G_U - L_{Radar} - L_U - L_P - L_L - FDR \tag{A-1}$$

Where:

I^U = Received interference power at the output of the unlicensed device antenna (dBm);
P_{Radar} = Peak power of the radar (dBm);
G_{Radar} = Antenna gain of the radar in direction of the unlicensed device (dBi);
G_U = Antenna gain of the unlicensed device in direction of the radar (dBi);
L_{Radar}= Radar transmit insertion loss (dB);
L_U = Unlicensed device receive insertion loss (dB);
L_P = Propagation loss (dB);
L_L= Building and non-specific terrain losses (dB);
FDR = Frequency dependent rejection (dB).

Equation A-1 is calculated for each unlicensed device in the distribution. The value obtained is then compared to the DFS detection threshold under investigation. Any unlicensed device for which the threshold has been exceeded will begin to move to another channel, and thus is not considered (for the remainder of the analysis) in the calculation of interference to the

15. Recommendation ITU-R M.1461, *Procedures for Determining the Potential for Interference Between Radars Operating in the Radiodetermination Service and Systems in Other Services*, at Annex 1 (2000).

radar, as given by Equation A-2.

$$I^{RADAR} = P_U + G_U + G_{Radar} - L_U - L_{Radar} - L_P - L_L - FDR \qquad \text{(A-2)}$$

Where:

I^{RADAR} = Received interference power at the input of the radar receiver (dBm);
P_U = Power of the unlicensed device (dBm);
G_U = Antenna gain of the unlicensed device in the direction of the radar (dBi);
G_{Radar} = Antenna gain of the radar in the direction of the unlicensed device (dBi);
L_U = Unlicensed device transmit insertion loss (dB);
L_{Radar} = Radar receive insertion loss (dB);
L_P = Radiowave Propagation loss (dB);
L_L = Building and non-specific terrain losses (dB);
FDR = Frequency dependent rejection (dB).

Using Equation A-2, the values are calculated for each unlicensed device being considered in the analysis that has not detected energy from the radar in excess of the DFS detection threshold. These values are then used in the calculation of the aggregate interference to the radar by the unlicensed devices using Equation A-3.

$$I^{AGG} = \sum_{j=1}^{N} I_j^{RADAR} \qquad \text{(A-3)}$$

Where:

I^{AGG} = Aggregate interference to the radar from the unlicensed devices (Watts);
N = Number of unlicensed devices remaining in the simulation;
I^{RADAR} = Interference into the radar from an individual unlicensed device (Watts).

It is necessary to convert the interference power calculated in Equation A-2 from dBm to Watts before calculating the aggregate interference seen by the radar using Equation A-3.

DESCRIPTION OF ANALYSIS PARAMETERS

The following subsections discuss each of the parameters used in the analysis model. These parameters include: unlicensed device and radar technical characteristics such as power and antenna gain, the radiowave propagation models, and frequency dependent rejection.

Radar Peak Power Level (P_{Radar})

The peak power levels of the radar that is used in this analysis is provided in Table A-2.

Radar Antenna Gain (G_{Radar})

The azimuth and elevation antenna pattern models for the radar are described earlier. The models give the antenna gain as a function of off-axis angle for a given main beam antenna gain. The radar mainbean antenna gain used in this assessment is provided in Table A-2.

Unlicensed Device Power Level (P_U)

As discussed earlier, the EIRP levels of the unlicensed devices considered in this analysis are 38 dBm and 6.6 dBm.

Unlicensed Device Antenna Gain (G_U)

The unlicensed device azimuth antenna pattern is omnidirectional and elevation antenna pattern model is provided in Table A-1.

Building and Non-Specific Terrain Losses (L_L)

The building and non-specific terrain losses include building blockage, terrain features, multipath. In the analysis this loss will treated as a uniformly distributed random variable between 1 and 10 dB for each radar unlicensed device path.

Radar and Unlicensed Device Transmit and Receive Insertion Losses (L_{Radar} and L_U)

The analysis includes a nominal 2 dB for the insertion losses between the transmitter and receiver antenna and the transmitter and receiver inputs for the radar and the unlicensed device.

Radiowave Propagation Loss (L_P)

To compute the radiowave propagation loss the NTIA Institute for Telecommunication Sciences Irregular Terrain Model (ITM) was used.[16] The ITM model computes radiowave propagation based on electromagnetic theory and on statistical analysis of both terrain features and radio measurements to predict the median attenuation as a function of distance and variability of the signal in time and space. The parameter values used in the ITM propagation model are provided in Table A-5.

16. National Telecommunications and Information Administration, NTIA Report 82-100, *A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode* (April 1982).

Table A-5. Description of ITM Parameter Values

Parameter	Description
Transmitter/Receiver Antenna Height	The unlicensed device antenna height varies based on a uniform distribution and the radar antenna height is 20 meters for this type of radar
Frequency	A nominal frequency of 5725 MHz
Polarization	Vertical polarization is used for the radar and unlicensed device.
Transmitter/Receiver Site Criteria	Random for the unlicensed device location Careful for the radar location
Delta H	90 m
Surface Refractivity	301
Dielectric Constant	15
Conductivity	0.005
Radio Climate	Continental Temperate
Percent Time/Location/Variability	Variable between 1 to 99 % based on a uniform distribution
Mode of Variability	Single message mode, which combines location and time variability into a single variability
Distance	Variable depending on the path under consideration which is determined by the random placement of the unlicensed device and radar locations

For each transmitter/receiver path, the ITM model is used to compute the propagation loss as a function of three random variables: distance, antenna height for the unlicensed device and mode variability. The distance depends on the random placement of the unlicensed devices with respect to the radar. The antenna height for each unlicensed device is randomly selected using a uniform probability distribution. The time/location variability is chosen randomly for each path based on a uniform probability distribution.

Frequency Dependent Rejection

Frequency Dependent Rejection (FDR) accounts for the fact that not all of the undesired transmitter energy at the receiver input will be available at the detector. FDR is a calculation of the amount of undesired transmitter energy that is rejected by a victim receiver. This can be found in Recommendation ITU-R SM.337-4 Annex 1.[17]

FDR can be stated mathematically as:

$$FDR = 10\log_{10}\left[\frac{\int_0^\infty p(f - f_{tx})df}{\int_0^\infty p(f - f_{tx})h(f - f_{rx})df}\right] \qquad \text{(A-4)}$$

17. Recommendation ITU-R SM.337-4, *Frequency and Distance Separations* (1948-1951-1953-1963-1970-1974-1990-1992-1997).

Where

f_{tx} = Undesired transmitter tuned frequency;

f_{rx} = Victim receiver tuned frequency;

$p(f - f_{tx})$ = Normalized emission spectrum of the undesired transmitter;

$h(f - f_{rx})$ = Normalized transfer function of the victim receiver;

f = Absolute frequency.

Numerical integration and convolution routines can be used to solve equation A-4.

In the special case of an undesired transmitter operating co-channel to a victim receiver, the following simplified form may be used:

$$FDR = \max\left(0, 10\log_{10}\left(\frac{B_{tx}}{B_{rx}}\right)\right) \tag{A-5}$$

Where

B_{tx} = Emission bandwidth of the undesired transmitter;

B_{rx} = Input bandwidth of the victim receiver.

The analysis model only considers co-channel operation of the radar and unlicensed devices, therefore Equation A-5 is used to compute the FDR.

RADAR INTERFERENCE PROTECTION CRITERIA

The desensitizing effect, on a radar system from other services of a noise-like type modulation such as those from the unlicensed devices is predictably related to its intensity. In any azimuth sectors in which such interference arrives, its power spectral density can, to within a reasonable approximation, simply be added to the power density of the radar receiver thermal noise.

The interference-to-noise (*I/N*) ratio is determined by comparing the interference power (I) to the receiver noise power, which is given by:

$$N = -114\,\text{dBm} + 10\log(B_{IF}) + NF \tag{A-6}$$

Where:

N = Receiver noise level (dBm);

B_{IF} = Receiver bandwidth (MHz);

NF = Receiver noise figure (dB).

Recommendation ITU-R M.1461 states that if no specific *I/N* ratio is provided for a given radar, the protection criterion of $I/N = -6$ dB should be used. This protection criterion applies 100% of the time. The contribution of the output from an unlicensed device that has detected the radar and has begun to move from the affected channel should not be considered in calculating the aggregate interference power at the radar receiver input.

DFS DETECTION THRESHOLD

As discussed earlier, the Commission is proposing to use a detection threshold based on a level that is 30 dB above the thermal noise measured in a 1.25 MHz bandwidth. Using Equation A-6, the thermal noise is:

$$N = -114 + 10 \text{ Log } (1.25) + 0 = -113 \text{ dBm}$$

The detection threshold is then found to be: -113 + 30 = -83 dBm. This detection threshold will be used in the assessment.

SPECIFIC MODELING PARAMETERS FOR TRACKING RADARS

This analysis considers ground-based tracking radars. The analysis model distributes unlicensed device locations randomly within the circular region described earlier. Initially the radar will be located along a straight line starting at the center of the circle (0 km) and extending to the end of the circle (24 km) in 4 km increments: 4 km, 8 km, 12 km, 16km, 20 km, and 24 km.[18] The analysis begins by placing the radar at one of these six locations. At each of the six locations one of five azimuths: 0, 45, 90, 135, and 180 degrees are used. For each starting azimuth, the analysis then begins calculating I^U for each unlicensed device, assuming the main beam of the radar antenna is pointing at 0 degrees elevation in the direction of the starting azimuth. The analysis then proceeds to compare each individual value of I^U to the DFS detection threshold. For each I^U that exceeds the DFS detection threshold, the corresponding unlicensed device is eliminated from further consideration during the analysis. The probability of DFS detection is 100% when the detection threshold is exceeded.[19] I^{RADAR} is then calculated for each unlicensed device remaining in the analysis, and is then used to calculate I^{AGG}. The radar elevation angle is then incremented by one degree and the calculations are repeated. This process is continued until the main beam of the radar antenna is pointing directly at the zenith (elevation = 90 degrees). The analysis then continues the calculations by decrementing the elevation angle one degree at a time. In that way, this process provides simulation of the radar's tracking of a target from horizon-to-horizon, passing directly overhead. That is the initial model run for 0 degrees elevation of the radar antenna, the location and antenna height of each unlicensed device is selected. Also, the building and non-specific terrain loss factor and the propagation variability for each radar-to-unlicensed device propagation path are selected. These factors do not change as the radar antenna pointing angle is moved from horizon-to-horizon. Only the antenna gain values change according to elevation angle. If the DFS threshold is exceeded at a specific elevation angle, that unlicensed device is moved to another channel for the

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18. Because the unlicensed devices are distributed uniformly, the actual location of the tracking radar is not believed to be a critical parameter in the analysis provided that a sufficient number of radar locations and starting azimuths are considered.

19. ITU-R M.1652 at Annex 4.

remainder of the horizon-to-horizon analysis. These aggregate values are then used to calculate the I/N ratio and an example are plotted as shown in Figure A-2.

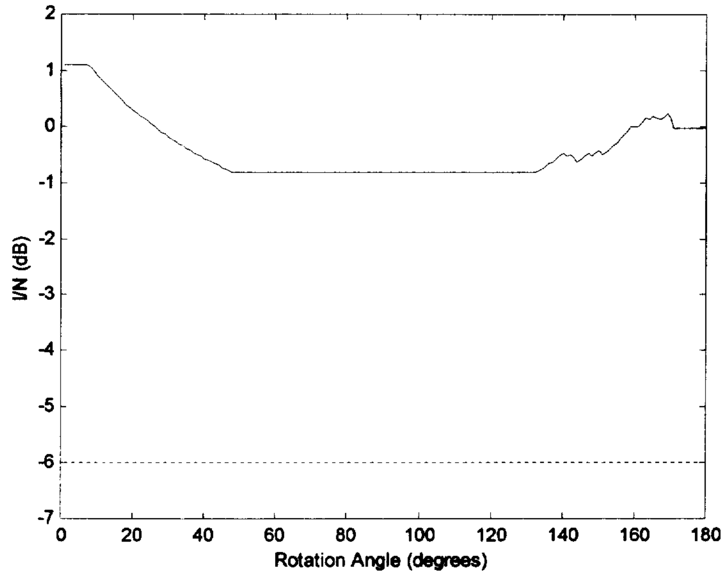

Figure A-2.

Based on the radar locations and starting azimuths described above, there was very little variation in the analysis results based on the placement of the radar and the starting azimuth. The I/N values were found to be slightly higher when the radar was positioned at the edge of the circle defining the unlicensed environment and the starting azimuth was 180 degrees (e.g., pointed away from the unlicensed device environment). This radar position and starting azimuth are used in the analysis to assess potential interference to the radar system.

The number of co-channel, simultaneously transmitting, unlicensed devices considered in the analysis was: 100, 500, and 1000. In order to develop statistics 100 iterations of the model were generated. For each iteration the following parameters are randomly varied: unlicensed device location, antenna heights of the unlicensed devices, propagation losses, and losses due to non-specific terrain effects. Based on the 100 iterations, a mean, median, and standard deviation are computed.

ANALYSIS RESULTS

Figures A-3 through A-5 present analysis results with half of the devices operating at the higher proposed power level of 38 dBm and half operating at the lower proposed power level of 6 dBm. The antenna heights of the unlicensed devices are randomly varied between 40 and 100 meters. The transmitter bandwidth of the unlicensed devices is 1 MHz.

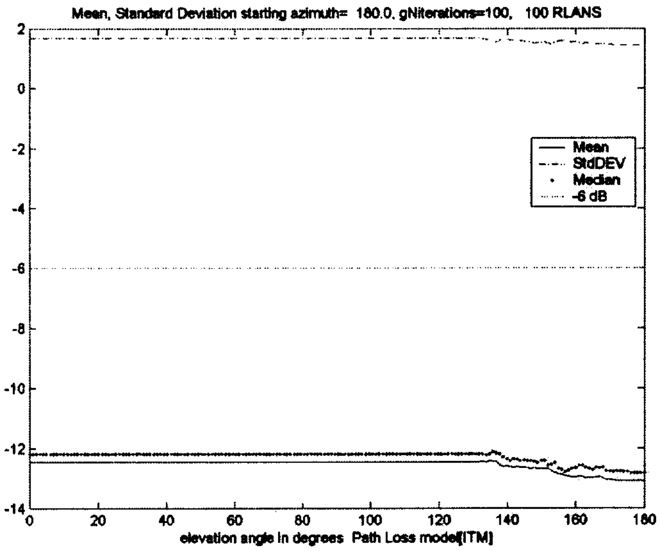

Figure A-3.

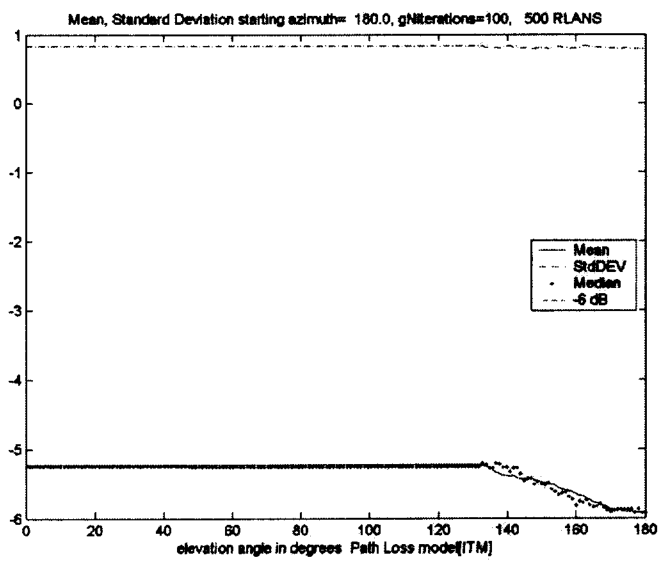

Figure A-4.

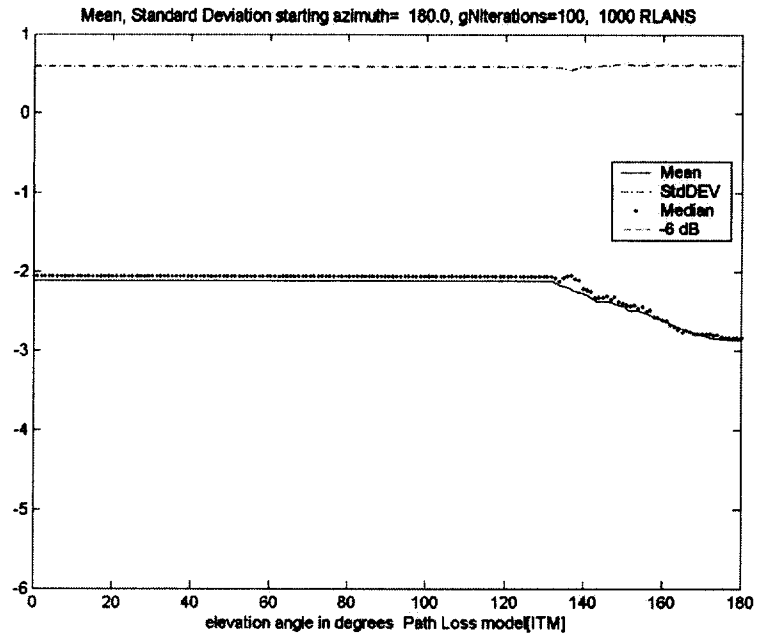

Figure A-5.

Figures A-6 through A-8 present analysis results with half of the devices operating at the higher proposed power level of 38 dBm and half operating at lower proposed power level of 6 dBm. The antenna heights of the unlicensed devices are randomly varied between 40 and 100 meters. The transmitter bandwidth of the unlicensed devices is 6 MHz.

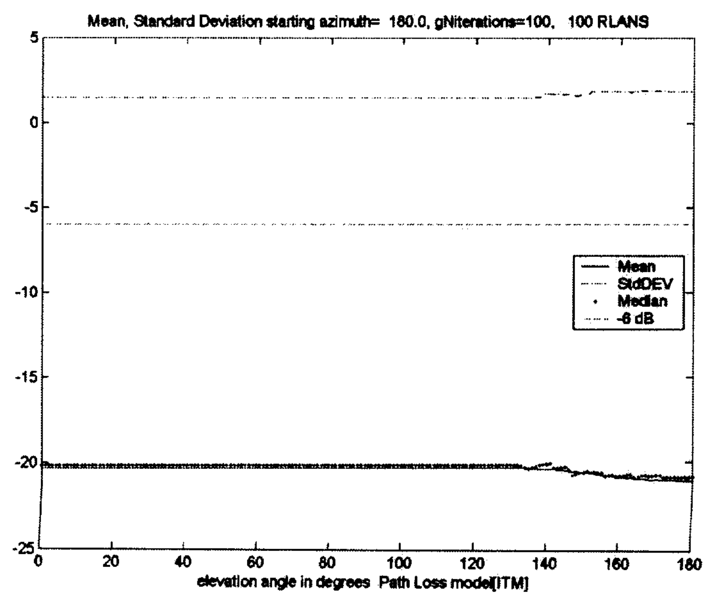

Figure A-6.

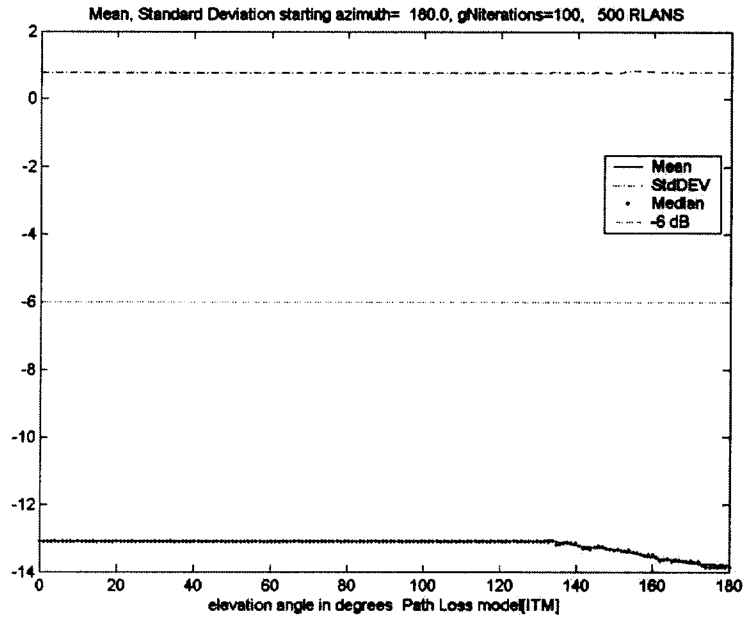

Figure A-7.

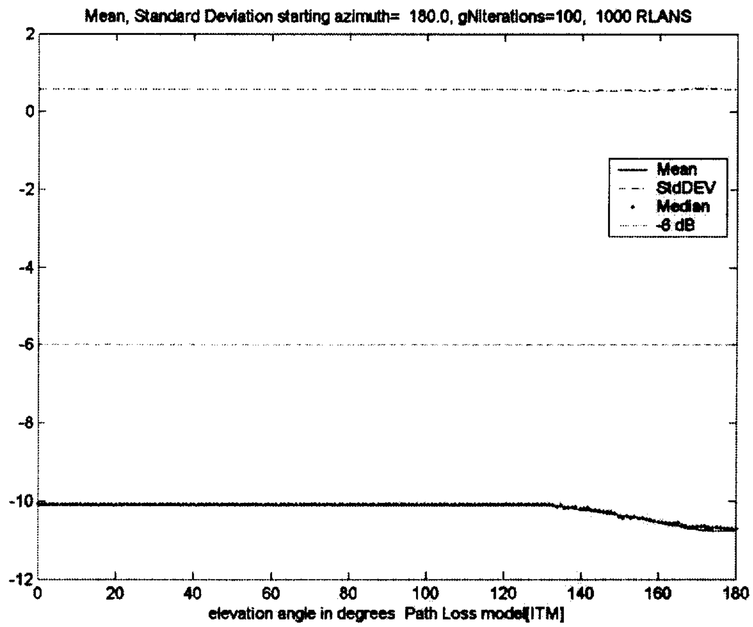

Figure A-8.

Figures A-9 through A-11 present analysis results with half of the devices operating at the higher proposed power level of 38 dBm and half operating at the lower proposed power level of 6 dBm. The antenna heights of the unlicensed devices are randomly varied between 40 and 100 meters. The transmitter bandwidth of the unlicensed devices is 18 MHz.

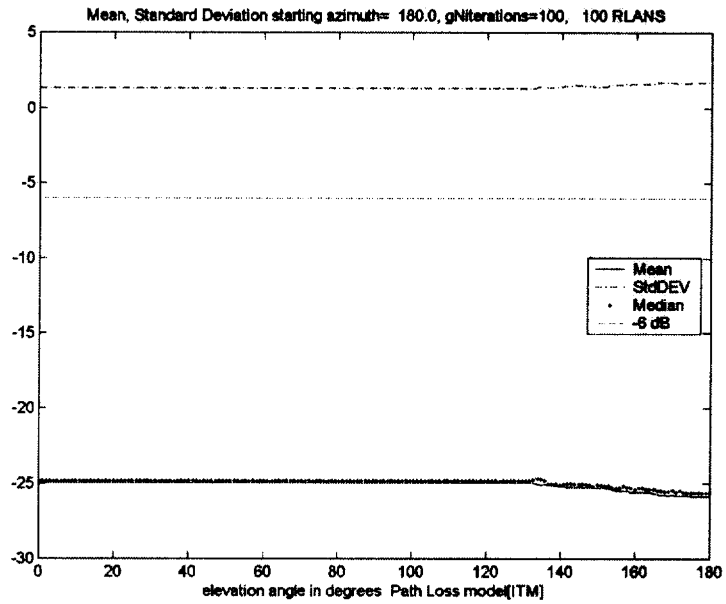

Figure A-9.

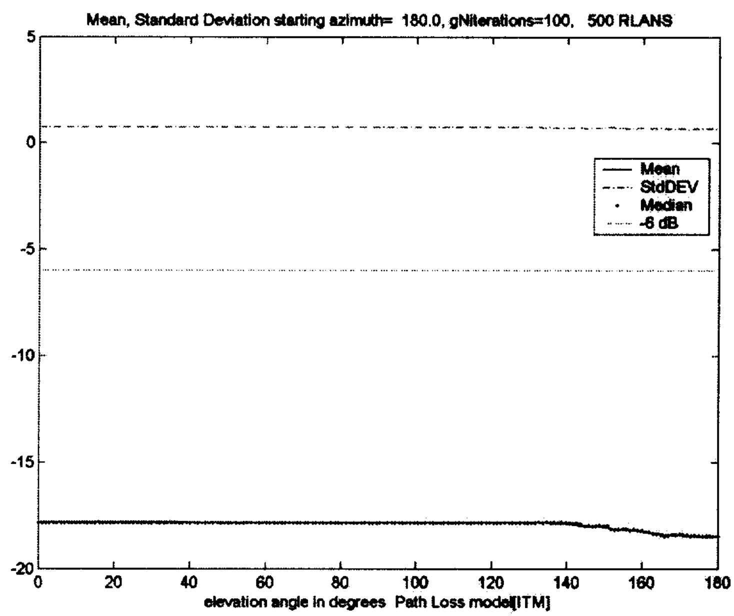

Figure A-10.

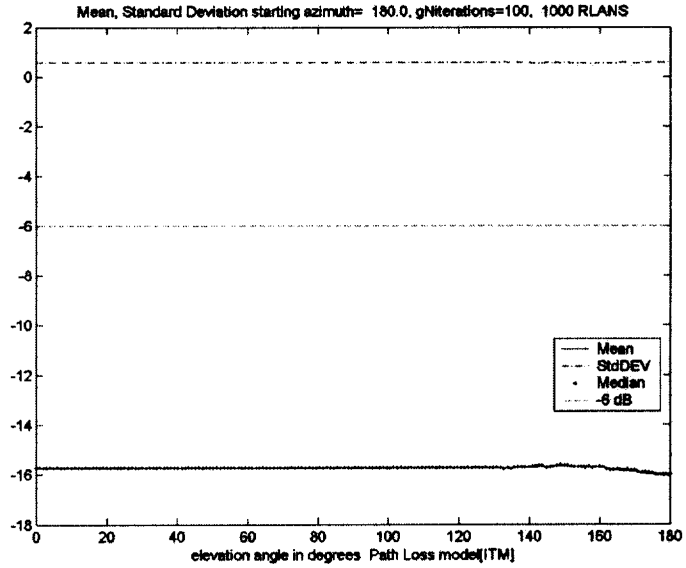

Figure A-11.

Figures A-12 through A-14 present analysis results with all of the devices operating at the higher proposed power level of 38 dBm. The antenna heights of the unlicensed devices are randomly varied between 40 and 100 meters. The transmitter bandwidth of the unlicensed devices is 1 MHz (Figures A-12), 6 MHz (Figures A-13), and 18 MHz (Figures A-14).

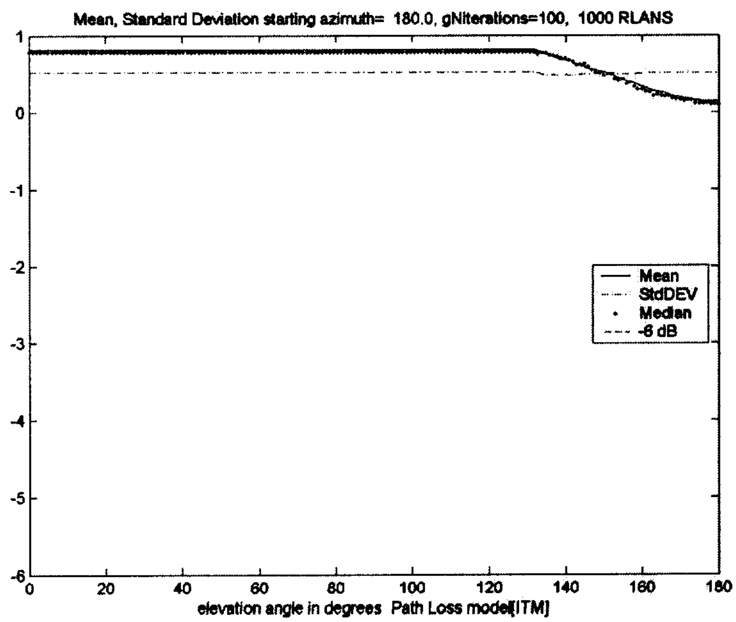

Figure A-12.